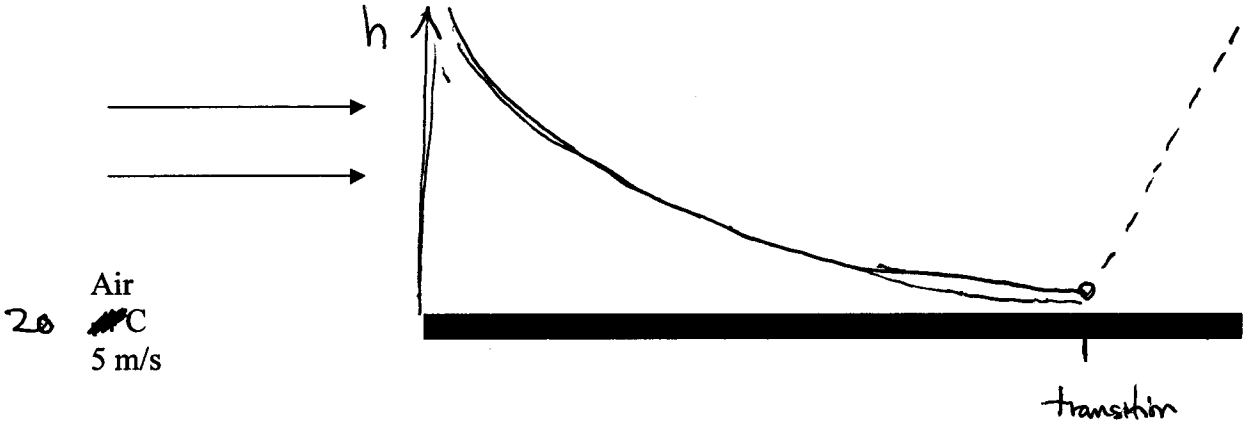
EM-415 Heat Transfer Exam #3 Name: SOLUTIONS

Problem 1) Heat transfer coefficients are in general greater for free than forced convection, and greater for water than air. In this problem we are going to compare the rate of heat loss from a flat plate exposed to forced air convection, versus free convection from a vertical plate in water. The plate is held at a constant temperature of ~~30~~ 35 °C in both cases.

a) (10 pts) Calculate the Reynolds Number and ~~plot~~ sketch the heat transfer coefficient versus position along the 2 m length of the plate



Air @ 300K

$\nu = 15.89 \times 10^{-6}$ $Pr = 0.707$

$k_f = 0.0263$ $Re = \frac{U_\infty L}{\nu} = 6.293 \times 10^5$

b) (20 pts) Calculate the total rate of heat loss per unit width for the plate. The plate is held at a constant temperature of 30 °C.

Mixed BL Conditions

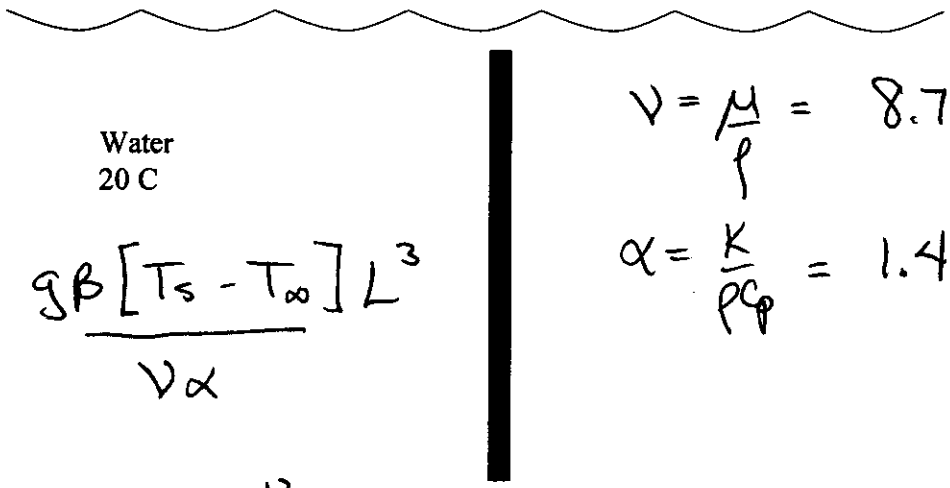
Eq. 7.41

$\overline{Nu}_L = (0.037 Re_L^{4/5} - 871) Pr^{1/3} = 659.9$

$\bar{h} = \frac{\overline{Nu}_L}{L} \cdot k_f = 8.68 \ W/m^2K$

$q = 2\bar{h} L [T_p - T_\infty] = 486 \ \frac{W}{m}$

c) (20 pts) The same 2 m long plate held at 30 C is then placed vertically into a body of water. Calculate the rate of heat loss due to free convection. The following properties are given for water: ($\mu = 855 \times 10^{-6}$ N·s/m^2, $\rho = 997$ Kg/m^3, $k = 0.613$ W/m·K, $C_p = 4179$ J/KgK, $\beta = 276.1 \times 10^{-6}$ 1/K and Pr = 5.83)



$$\nu = \frac{\mu}{\rho} = 8.75 \times 10^{-7}$$

$$\alpha = \frac{k}{\rho C_p} = 1.47 \times 10^{-7}$$

$$Ra_L = \frac{g\beta[T_s - T_\infty]L^3}{\nu\alpha}$$

$$Ra_L = 2.358 \times 10^{12}$$

$$\overline{Nu}_L = C Ra_L^{\,n} = 0.10 (Ra_L)^{1/3}$$

$$\overline{Nu}_L = 1331 = \frac{\bar{h}L}{k_f} \Rightarrow \bar{h} = 407.9 \frac{W}{m^2 K}$$

$$\frac{q}{W} = 2\bar{h}L[T_s - T_\infty] = 22.8 \text{ kW}$$

* Equation 9.26 also applicable

d) (5 pts) Why do scuba divers need to wear wetsuits when spending long periods of time underwater even when the water temperature is greater than 80 F.

$h_{free\ in\ water} >> h_{forced\ air}$ due to high k_f of water

Give two reasons why this is not necessarily true for when snorkeling under similar conditions. Assume the air and water are at the same temperature.

less area exposed to water

Solar radiation

Problem 2) Hot exhaust gases from the gas turbine generator on our ship are used to preheat the air entering the combustion chamber. This is accomplished using a cross flow heat exchanger where the hot exhaust gases are passed over pipes that contain the intake air for the Turbine. Therefore the exhaust gases are mixed while the intake air is unmixed in tubes. The exhaust gases enter the heat exchanger at 800 K and exit at 600 K. The total mass flow rate for both the intake air and the exhaust gases is 10 Kg/s. The intake air enters the heat exchange at 300 K. (Evaluate the properties for the intake air at 400 K). There are 100 thin walled tubes, each tube is 6 m long and 4 cm in diameter

$\Delta T_1 = 288$

$\Delta T_2 = 300$

a) Calculate the rate of heat exchange between the two fluids and the outlet temperature of the intake air.

using 700K

$q = \dot{m} C_{p,\text{exhaust}} \Delta T$

$C_p = 1075$ J/kg K

$C_p = 1014$ J/kg K

$q = 2.15$ MW

$T_i = 800K$ $T_o = 600K$ $t_i = 300K$

$t_o = 512$ K

$A = 100 \times \pi D L$

b) Calculate the Overall Heat Transfer Coefficient

$q = UA \Delta T_{lm}$ $\Delta T_{lm,CF} = 294\,^\circ C$ $R = 0.94$

$A = 754\ m^2$

$U = 102.2\ W/m^2K$ $\Delta T_{lm} = 279\,^\circ C$ $P = 0.42$

$F = 0.95$

c) Determine the heat transfer coefficient of the air flowing **inside** the tubes. assume *

$Pr = 0.69$

$k_f = 0.0338$

$Re = \frac{4\dot{m}}{\pi D \mu} = 1.38 \times 10^5$ Turbulent

2m >> 4cm ✓ Fully Developed

$Nu_D = 0.023 Re_D^{4/5} Pr^{0.4} = 256$ $h = 216.8$

d) Determine the heat transfer coefficient for the air outside the tubes. (Hint: you should not need a correlation for this calculation)

$\frac{1}{U} = \frac{1}{h_i} + \frac{1}{h_o}$

$h_o = 193.3\ W/m^2K$